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RESEARCH ON THE ASSYMETRICAL AERODYNAMIC FORCES OF REENTRY VEHICLES

by

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ABSTRACT This article goes through numerical trajectory equations with six degrees of freedom to simulate reentry vehicle or body asymmetrical aerodynamic forces and asymmetrical static and dynamic derivative influences on abnormalities in the rolls and turns of bodies or vehicles. It illucidates the mechanisms which produce asymmetrical aerodynamic forces and asymmetrical static and dynamic derivatives. This article makes use of approximate calculations set up by the author and numerical value calculation methods. It calculates classical asymmetrical aerodynamic forces for reentry bodies. It does qualitative analyses of the patterns or rules associated with aerodynamic forces as they follow changes in the geometrical parameters of vehicles or bodies, having important reference value for the design of reentry bodies or vehicles.

KEY TERMS Reentry Vehicle, Aerodynamic Stability, Aerodynamic Derivative, Aerodynamic Force Calculation

I. INTRODUCTION

Through observations of flight tests, it was discovered that reentry bodies show the appearance of phenomena associated with abnormal roll. In 1960, the British BK-9, at low altitude, showed the appearance of divergence in angles of attack which resulted in the destruction of the body or vehicle. In 1960, the U.S. MK-12 also produced the same type of destruction incident. In 1975, the MK-400 also showed the appearance of lateral overload phenomena. Because of this, workers in flight mechanics and aerodymanics did a large amount of research work on such problems in dynamics as small body or vehicle roll abnormalities, divergent angles of attack, roll speeds past zero, and other similar problems[1].

This article pays important attention to research on questions of asymmetrical aerodynamics related to reentry body or vehicle roll abnormalities, divergent angles of attack, and roll speeds passing zero.

As far as initial research on reentry bodies is concerned, when solving linear aerodynamic motion equations for states with zero angles of attack, one assumed that the pitch and yaw directions were associated with forces and moments of force that are all zero and that the static and dynamic derivatives for the two directions were equal to each other [2-5]. Later, Maple and Synge [6] brought out the problem of asymmetrical aerodynamic damping associated with symmetrical bodies on missile tips. After that, in experiments and theory, further steps were taken to study this problem [7-13] in order to analyze assymetrical aerodynamic forces which are given rise to by small asymmetries in geometrical forms. A series of experiments was carried out on sharp cones, double cones, sherical cones, as well as nose tips with small asymmetries [14-16]. Theoretical research was also developed in continuous succession [17-20].

II. INFLUENCES OF ASYMMETRICAL AERODYNAMIC FORCES AND AERODYNAMIC DERIVATIVES ON BODY ROLL ABNORMALITITES

In order to do research on the influences of asymmetrical aerodynamic forces and aerodynamic derivatives on body or vehicle roll abnormalities, use was made of trajectory equations with six degrees of freedom.

(I) INFLUENCES ON ASYMMETRICAL AERODYNAMIC FORCES

When bodies or vehicles are flying with zero angles of attack, they possess pitch, yaw, and roll forces or moments of force which are called asymmetrical aerodynamic forces. It is possible to represent these as being C_{mo}, C_{no}, $C_{\eta o}$, C_{eo}... Although the magnitudes 46
are small, they have important influences on body or vehicle roll characteristics and will lead to the body or vehicle's continuous or sustained resonsance, temporary resonsance, and roll acceleration, moving on to instability and roll speed reductions even to the point of going past zero and other similar abnormal phenomena.

The body or vehicle mass eccentricity Δy = 1mm. Numerical value simulations are carried out respectively on the moment of pitch forces C_{mo} and the moment of yaw forces $C_{\eta o}$. Calculations clearly show that the roll speeds of bodies or vehicles and the

aerodynamic pitch frequencies (P_{crp}) or yaw frequencies (P_{ery}), when locked together in lengths of duration (See Fig.'s 1 and 2), have increases in lateral overloads across bodies or vehicles on missile tips (See Fig.3).

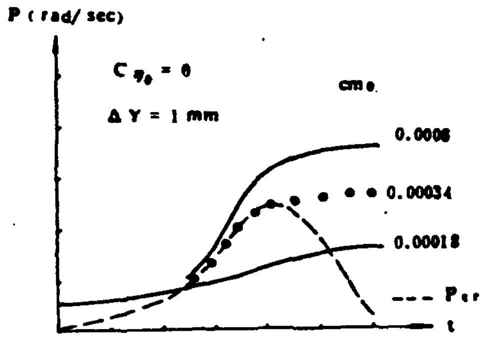

Fig.1 Assymetries Within Plane

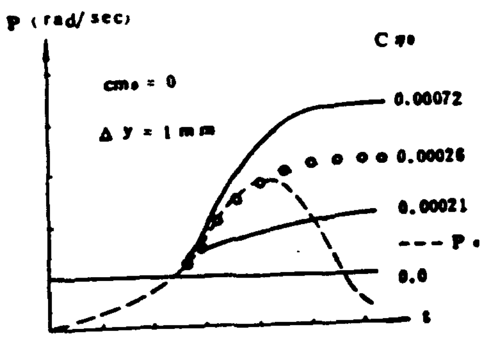

Fig.2 Assymetries Outside Plane

From Fig.1, it is possible to know that, taking C_{mo} = 0.00034, (C_{mo} = 0), the pitch frequency P_{crp} and the roll frequency of missile tip bodies or vehicles are locked together, and lateral overload across the body or vehicle on the missile tip increases. Fig.2 clearly shows that C_{no} = 0.00026, (C_{no} = 0), that yaw

frequency P_{cry} and roll frequency also show the appearance of interlocking, and that lateral overloads also increase, leading to structural destruction of the missile nose body or vehicle.

(II) INFLUENCES OF ASYMMETRICAL AERODYNAMIC DERIVATIVES

Equation simulations with six degrees or dimensions of freedom clearly show that asymmetrical static and dynamic derivatives do not uncommonly give rise to key effects in determining whether or not roll is produced in missile top bodies or vehicles. This being the case, when missile nose bodies or vehicles showing the appearance of roll is common, asymmetrical static and dynamic derivatives have important influences on the peak values for trim angles of attack and peak values for lateral overload.

1. INFLUENCE OF ASYMMETRICAL STATIC DERIVATIVES (THAT IS, $C_{ma} \neq C_{\eta\beta}$)

When reentering bodies or vehicles show the appearance of roll, the derivative C_{ma} associated with moments of force versus angles of attack within the pitch plane and derivative $C_{\eta\beta}$ associated with moments of force versus side slip angle β within the yaw plane are not equal to each other. Following increases in G_1 ($=C_{ma}/C_{\eta\beta}$), peak values for trim angles of attack increase (See Fig.4). In the Fig.,

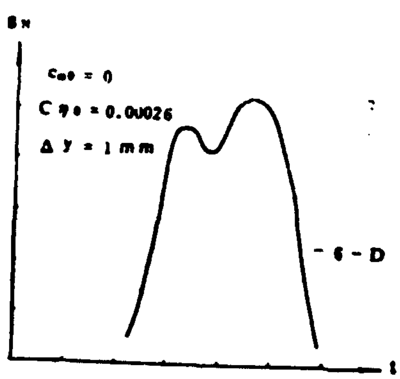

Fig.3 Lateral Overloads Associated With Roll Abnormalities

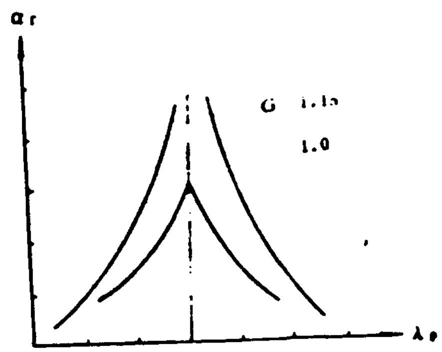

Fig.4 Influence of Asymmetrical Derivatives

a_T is the overall or general angle of attack for trim, and λ_p is a comparison of pitch frequency and roll frequency.

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2. THE INFLUENCES OF ASYMMETRICAL DYNAMIC DERIVATIVES (THAT IS, $C_{mq} + C_{m\dot{a}} = C_{\eta r} - C_{\eta\dot{\beta}}$)

Asymmetrical dynamic derivatives and asymmetrical static derivatives have similar effects. The cases are the same as those for other parameters. When $G_2 = 1$, $|a_T| = 11.8^{\circ}$, and taking $G_2 = 1.1$, $|a_T| = 14.1^{\circ}$. That is to say that, when the bodies or vehicles of missile tips show the appearance of roll abnormalities, following along with increases in G_2 $(=(C_{mq} + C_{m\dot{a}})/(C_{\eta r} + C_{\eta\beta}))$, peak values for the overall trim angle of attack $|a_T|$ associated with roll resonance increase. This conclusion is in line with the conclusions in Reference [17].

III. MECHANISMS FOR THE PRODUCTION OF ASYMMETRICAL AERODYNAMIC FORCES AND ASYMMETRICAL DERIVATIVES

In order to solve the problems associated with missile nose body

or vehicle roll abnormalities, there is a need to study the mechanisms producing asymmetrical aerodynamic forces and aerodynamic derivatives.

1. ASYMMETRY IN NOSE SECTIONS

In the process of missile nose reentry, due to asymmetrical ablation shapes produced by the random distributions of coarseness on the surface of missile nose bodies or vehicles or due to asymmetries produced by processing of geometrical shapes, in all cases, one will see created asymmetries of pressure distributions and flow field parameters. Even if the angle of attack is zero, they will also produce asymmetrical aerodynamic forces and aerodynamic derivatives.

This article makes use of the methods of the author in Reference [21], calculating classic asymmetrical nose section flow fields. Results adequately explain that, in a situation where $a = 0^{\circ}$, the small asymmetries in the nose section cause flow fields to be nonuniform, and, in conjunction with that, there are obvious influences on the rear fuselage (See Fig.5). In the case where the rear fuselage pressure distribution $\varphi = 0^{\circ}$ and the two meridian planes at 180° are within 30 times the radius of the nose section (z/R_N=30), pressure distributions have definite differences. Results show the appearance of C_{mo} and $C_{\eta o}$ (See Table 1).

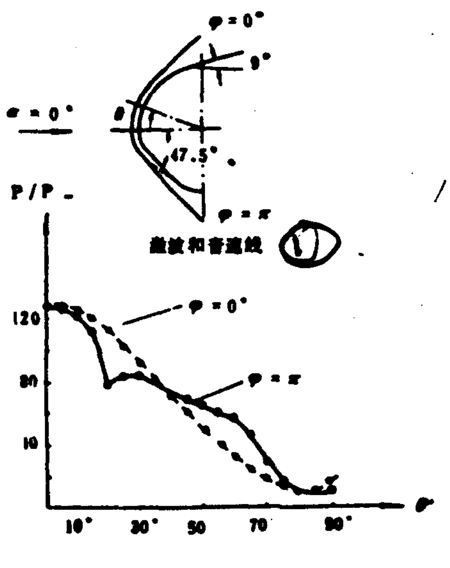

Fig.5 Pressure Distributions for Asymmetrical Object Nose Section Surfaces of $47.5^{\circ}/9^{\circ}$ (1) Shock Wave and Sonic Curve

2. ASYMMETRIES IN ABLATION GROOVES, PATTERNS, AND THERMAL EXPANSION

There are mutual effects between the striation patterns and grooves or troughs of the ablated forms of missile noses and exterior flow fields. These produce asymmetrical aerodynamic forces. In wind tunnels, use was made of low temperature ablation materials (camphor) to study moments of roll force given rise to by ablated troughs or grooves or by striation patterns [22]. When $a = 0^{o}$, and moments of roll force appeared, the roll produced by ablated grooves, troughs or striation patterns is the result of the collected patterns of ablated surfaces and the effects of exterior flows [23]. When the ablated tips of reentering missiles have not yet formed troughs, grooves or striation patterns and the surfaces are still smooth, due to the fact that the thermal expansion of the materials on the missile body is not uniform, pressure distributions on the circumference are asymmetrical. This is also capable of producing moments of roll forces.

Z/RN	2	5	10	20	30	40
C_{n_0}	0.00044	0.00204	0.00127	0.00104	0.00105	0.00096
C_{m_0}	0.00038	0.00170	0.00082	0.00067	0.00071	0.00063

Table 1

3. ASYMMETRY OF BOUNDARY LAYER DISPLACEMENT THICKNESS

When the tips of reentering missiles roll, boundary layer displacement thicknesses are asymmetrical. The mutual effects with exterior flow fields are associated with circumferential pressure distributions around the missile fuselage which are not symmetrical. This leads to the production of small, asymmetrical aerodynamic forces.

4. ASYMMETRICAL BOUNDARY LAYER TRANSITIONS

Due to nonuniformities in the processing of the body of missiles and nonuniform distributions of coarseness on surfaces, it leads to asymmetrical boundary layer transitions. This type of mutual effect between boundary layers and exterior flow fields makes pressure distributions asymmeterical[24]. Flight tests of 5 reentering missile tips discovered that, in boundary layer transition periods, they all produced excessive divergence in angles of attack[25].

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5. NONLINEAR EFFECTS IN NONVISCOUS FLOWS

Going through experimental studies of sharp cones and blunt spherical cones[16] [26], it is possible to clearly show the effects of aerodynamic forces from degrees of bluntness of a nonlinear nature. The tests on sharp cones clearly showed that, when the angle of attack equals the semiconic or hemipyramid angle, $-C_{ma} = C_{\eta\beta}$, $C_{mq} + C_{m\dot{a}} = C_{\eta r} - C_{\eta\dot{\beta}}$. When the angle of attack is half the conic or pyramid angle, then it produces asymmetry. Tests on blunt spherical cones clearly show that, taking the bluntness ratio to be 0.25, a = 5°, and $C_{\eta\beta} = 1.8\ (-C_{ma})$, clearly showing that the derivative for the moment of force C_{η} associated with the yaw plane versus β is not equal to the derivative for the moment of forces C_m associated with the pitch plane versus a.

6. CONICAL MOTION

When symmetrical missile tip winding velocity vectors make conical motions, on the leeward surfaces one has the appearance of asymmetrical vortices, leading to aerodynamic derivatives that are asymmetrical. Reference [7] uses six component strain balances to measure lateral moments of force produced by conical motions. In conjunction with this, photographs were made of the asymmetrical vortices.

IV. INFLUENCES OF MISSILE NOSE GEOMETRICAL PARAMETERS ON ASYMMETRICAL AERODYNAMIC FORCES

Slightly asymmetrical aerodynamic forces produce key parameters associated with abnormal roll. When abnormal roll occurs, asymmetrical static and dynamic derivatives influence peak values for trim angles of attack. In order to lower the probability of the occurence of abnormal roll, it is easy to see that there is a need to reduce small asymmetrical aerodynamic forces. Going through approximation calculations[27] and numerical value calcuations[21], one obtains patterns for changes in small asymmetrical aerodynamic forces as they follow the missile tip bluntness ratio (R_N/R_B), semiconic or hemipyramid angle (θ c(illegible), degree of static stability, and M number. In order to make comparisons with experimental data that is already available, this article selected the experimental model in AEDC-TR-72-52 (See Fig.6). In order to empirically verify calculation methods, we calculated C_m for different exterior forms with M = 8 and subsequent changes in angles of attack (See Fig.7). The results clearly show that the two agree relatively well when other parameters are fixed. The small asymmetrical aerodynamic force C_{mo} follows increases in the bluntness ratio (R_N/R_B) and increases (See Fig.8). Under conditions with the same type of bluntness ratios, the semiconic or hemipyramid angle (illegible) gets smaller. C_{mo} increases (See Fig.9). The degree of static stability increases, and C_{mo} gets smaller (See Fig.10).

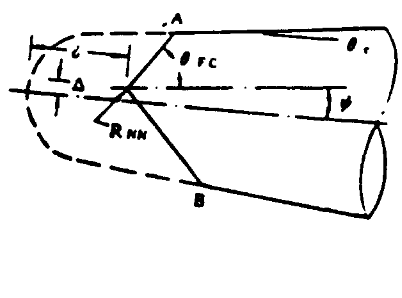

Fig.6 Asymmetrical Nose Section Shapes

The calculation results described above clearly show that, when one calculates missile tips, one selects small bluntness ratios, large conic or pyramid angles, appropriate increases in static degrees of stability, and it is possible to very greatly reduce small

asymmetrical aerodynamic forces and moments of force. Because this is the case, one reduces the probability of the occurence of abnormal roll.

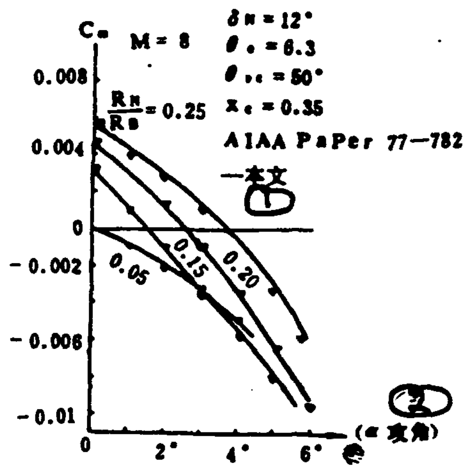

Fig.7 Changes in Asymmetrical Pitch Moments of Force Following $(M, R_N/R_B, a)$ (1) This Article (2) Angle of Attack

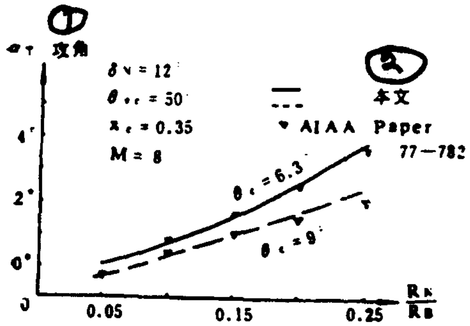

Fig.8 Changes in Asymmetrical Nose Section Trim Angles of Attack Following $(M, R_N/R_B, \theta_c)$ (1) Angle of Attack (2) This Article

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V. CONCLUSIONS

This article went through numerical value simulations of trajectory equations with six degrees of freedom. It illucidated the influences of asymmetrical aerodynamic forces and aerodynamic derivatives on abnormal roll states. It studied the mechanisms of production associated with asymmetrical aerodynamic forces and aerodynamic derivatives. It made use of the approximation

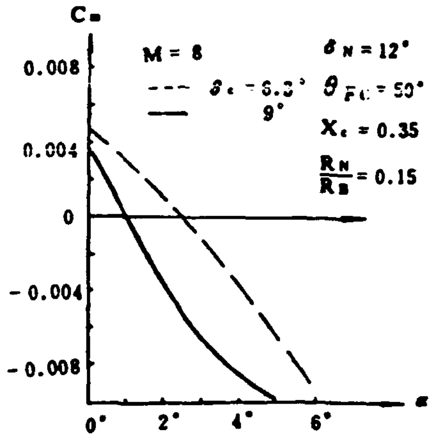

Fig.9 Changes in Asymmetrical Moments of Pitch Forces Following (N, c, a)

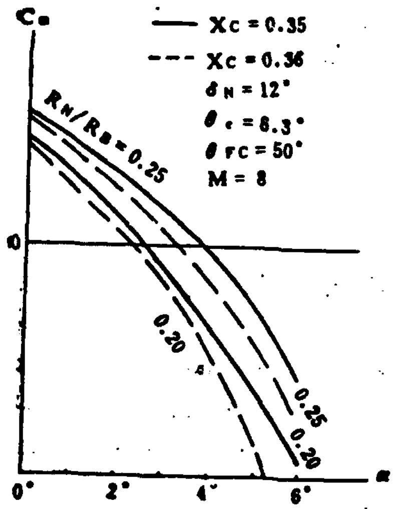

Fig.10 Changes in Asymmetrical Moments of Pitch Forces Following (R_N/R_B, X_C, a)

calculations and numerical value calculation methods set up by the author to carry out large amounts of calculations. It explored the rules or patterns for changes in asymmetrical aerodynamic forces following along with degrees of bluntness, semiconic or hemipyramid

angles, and degrees of static stability, and supplied important data for missile nose design.

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